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"Microstimulation of the Lumbosacral Spinal Cord"

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SUMMARY AND ABSTRACT

We modified the sacral cord microstimulating array, in order to better accommodate the anatomy of the implantation site in the sacral spinal cord. In the new design, six microelectrodes, 1.4 to 1.6 mm in length, extend from a single matrix button 3 mm in diameter. The bottom of the matrix is concave with a radius of curvature of 2 mm, in order to conform to the dorsal surface of the sacral cord. The array is further stabilized by a pair of uninsulated iridium anchoring pins, 3 mm in length, which extend nearly completely through the sacral spinal cord. We also modified the velocity profile of the sliding armature in the insertion tool, which is used to implant the array at a moderately high velocity (~ 1m/sec). We have implanted one array into a young male cat. The array inserted easily and was very stable after being implanted.

INTRODUCTION

Originally, we implanted individual iridium microelectrodes into the sacral spinal cord, in order to stimulate the neurons and axons of the preganglionic parasympathetic nuclei which innervate the urinary bladder's detrusor muscle. We found that these individual electrodes tended to dislodge from the cord after implantation, probably due to traction from the lead wires. We therefore incorporated 3 discrete iridium microelectrodes into a linear array extending from the elongated Epoxy matrix. Using a special insertion tool, the arrays were inserted vertically through the dorsal surface of the cord and medial to the dorsal roots, at a velocity of 1m/sec. This array has been more stable than the individual microelectrodes, but it has not been without its own problems. Variable amounts of tissue injury have occurred during insertion of the electrodes and/or during subsequent movement of their tips through the tissue. Although the electrodes were implanted at a fairly high velocity, the histologic evaluations and the videotapes taken at the time of implantation indicate that the spinal cord had dimpled and rotated slightly during electrode insertion, and this undoubtedly contributed to the tissue scarring in the gray matter and spongy changes in the long fiber track. Also, some of the electrodes did not strike their intended target in the intermediolateral cell column, and this targeting error was probably due to displacement

and rotation of the cord. These difficulties probably are related to the fact that the sacral spinal cord is very slender, and is very loosely suspended within the dural sac and the surrounding spinal roots. Also, the dorsal surface of the sacral cord is quite convex and does not easily accommodate an array matrix that has been inserted vertically. Finally, there is always some manipulation of the array cable, after the array is inserted and before it is secured to the dura. This dictates that the array should be anchored in the tissue as firmly as possible, immediately after implantation.

We have therefore redesigned the intraspinal array to better accommodate the geometry of the feline sacral spinal cord. Six electrodes extend from a single matrix button 3 mm in diameter. The bottom of the matrix is concave with a radius of curvature of 2 mm, to conform to the dorsal surface of the sacral cord. The array is further stabilized by a pair of uninsulated iridium anchoring pins, 3 mm in length, which extend nearly completely through the sacral spinal cord.

METHODS

The shafts of the discreet iridium microelectrodes are fabricated from pure iridium wire 50 μm in diameter (etched down from 125 μm). One end of each shaft is etched electrolytically to a cone with an included angle of 10° and with a blunt tip having a radius of curvature of 1.5-2.0 μm. After the tips have been shaped, a Teflon-insulated platinum lead wire is micro-welded to the shaft. The shafts is then insulated with 4 thin coats of Epoxylite electrode varnish. The insulation is removed from the tip of the shaft by an erbium laser to yield an active geometric surface area of 2,000± 400 μm^2. Next, the individual microelectrodes are assembled into arrays. A Teflon mold was fabricated that holds the tip end of each electrode and the two long stabilizing pins, in separate alignment tubes. Machining the mold's convex bottom to a radius of curvature of 2 mm was particularly challenging. The upper portion of the array matrix is encapsulated in medical grade two-part Epoxy (Masterbond AP21LY) to form the array's superstructure (matrix).

After extrusion from the mold, the top of the array's superstructure is held

against a vacuum wand, and with the aid of a special microscope eyepiece, the individual electrode shafts are aligned with the axis of the wand, so that they will not slash the tissue when they are inserted into the spinal cord. Finally, the individual platinum lead wires are then connected to the long quadrifilar cables which connect to the percutaneous connector, and the iridium electrodes are activated to increase their charge capacity.

Figure 1A and 1B are diagrams of the side and top of the array. It contains the 6 iridium microelectrodes which range in length from 1.4 to 1.6 mm and also the 2 long stabilizer pins, each 3 mm in length. The electrodes are arranged in 2 rows 1.7 mm apart. This is intended to place their tips within the intermediolateral cell column of the S2 sacral spinal cord when the array's concave bottom is centered over the cord's midline.

RESULTS

To date, one array has been implanted chronically. The cat was anesthetized with Halothane and nitrous oxide. The scalp was opened longitudinally in a midline incision and a percutaneous connector was affixed to the skull. The electrode array was tunneled subcutaneously to the sacral region, and the spinal cord was exposed from L5 to S3 with a standard dorsal laminectomy. The L5 dorsal spinal process was secured with a vertebral clamp and the spinal dura was opened in a longitudinal midline incision extending from S1 to S3. The S2 level of the cord was located by recording the dorsal cord potential while electrically stimulating the perigenital region, which is innervated from the S2 level of the cord. The arachnoid was then dissected from the spinal roots in the S2 region, so the roots could be retracted. The recording electrode was inserted through a separate small opening in the dura and passed approximately 4 cm caudally, so as to lie adjacent to the ventral roots. It was then secured to the dura with one additional suture. The recording reference electrode was secured to the outside of the dura at approximately the same level as the recording electrode.

The microelectrode array was then placed into the end of the stator tube (barrel) of inserter tool, where it is held against the armature by a vacuum. The orifice of the

stator tube was centered over the midline of the S2 cord, with the array cable extending rostrally. Figure 2A is a frame from the video tape, showing the inserter and array just prior to insertion. The array cable was secured loosely to the dural, approximately 2 cm rostral to the site. The end of the barrel was then used to depress the cord by approximately 1 mm prior to deploying the array, and the array was injected into the cord. We modified the insertion tool's velocity damping mechanism, so that the stabilizer pins and the microelectrodes penetrate the pia at a high velocity (> 1m/sec), in order to reduce the tendency of the cord to dimple as the dura is being penetrated. Then, near the end of the stroke, the insertion velocity decreases, so that the underside of the array matrix will not impact against the dorsal columns and the dorsal root entry zone. This velocity profile was achieved by replacing the tool's viscous damping system with a cylinder of closed-cell foam rubber.

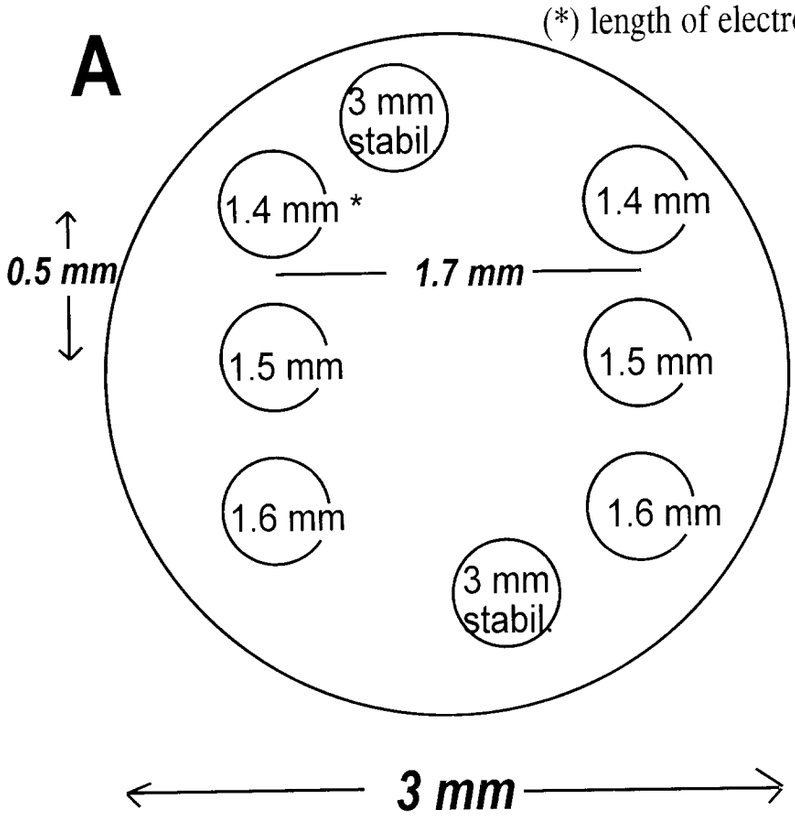
Figure 2B shows another video frame of the array after being inserted into the sacral cord. The electrodes appear to be fully inserted, and the array matrix is resting directly over the midline of the dorsal column. The two rows of microelectrodes can be seen within the transparent Masterbond matrix.

After inserting the array, a single 7-0 suture was passed through both margins of the dura and over the array cable, to hold it between the dorsal roots and close to the spinal cord. The dura was then closed loosely, with a pair of 7-0 sutures, and the lips of the cut dura were placed over the array matrix. The partially open dura was covered with a patch of fascia resected from the perispinal muscles. The platinum ground electrode was placed on top of the fascia patch. The perispinal muscles were then approximated with sutures and the skin was closed with staples.

After the end of the procedure, were able to evoked low-threshold responses in the ventral roots, while stimulating with at least 3 of the microelectrodes. Figure 3 shows a family of responses evoked from microelectrode 1. Threshold of the early response (E) was less than 6 μA. The late responses (L) probably represent neuronal activity evoked transsynaptically, or activity in slowly- conducting efferent axons.

The cat will undergo 24 hours of stimulation, approximately 28 days after the implant surgery, then be sacrificed for histologic examination of the array site.

(*) length of electrode, below matrix



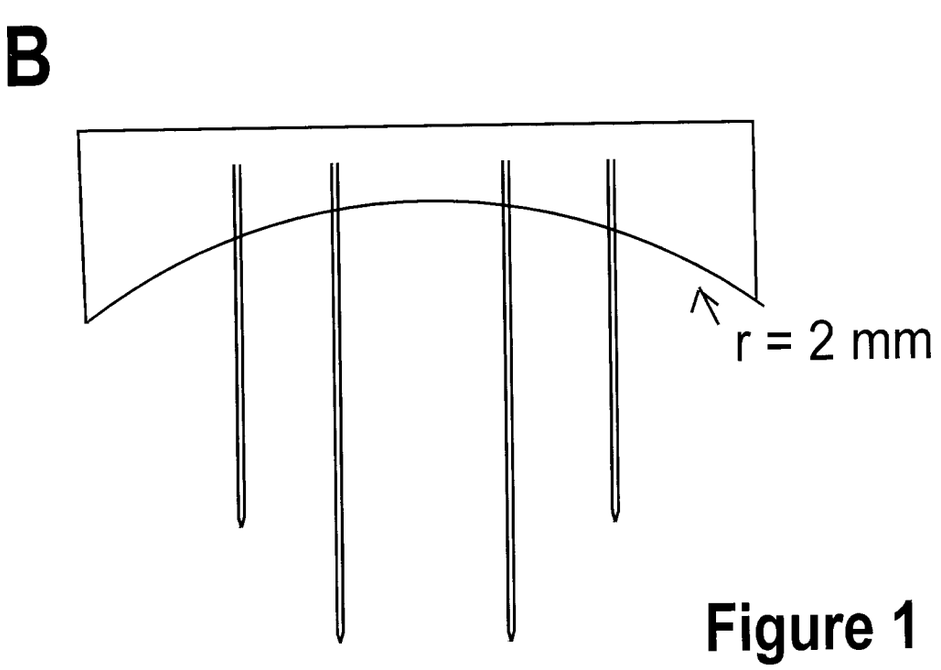


Figure 1

E:/SKW/6ELSPINL.SKD

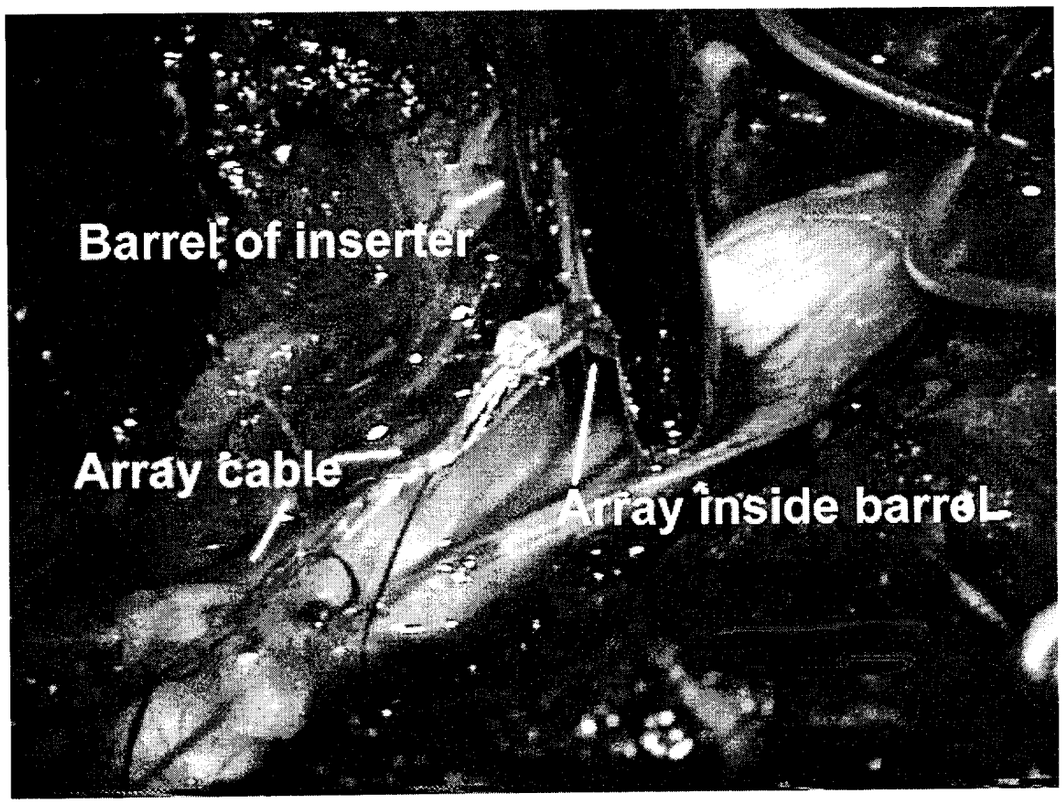


Figure 2A

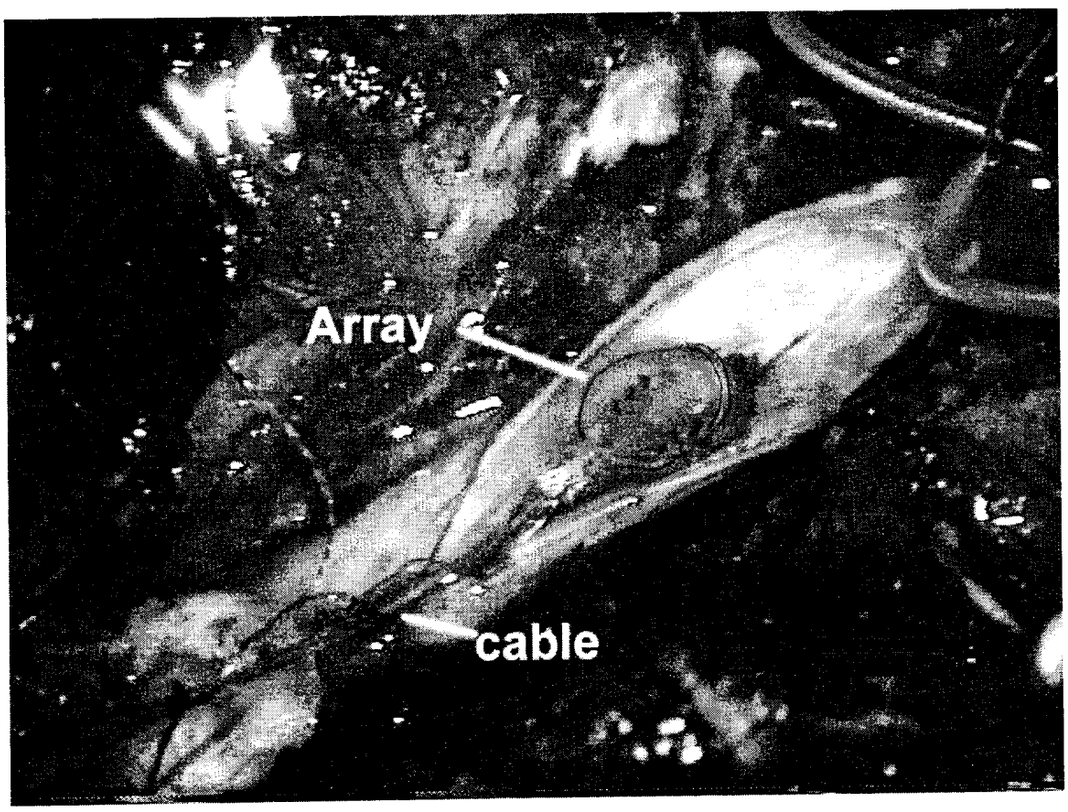
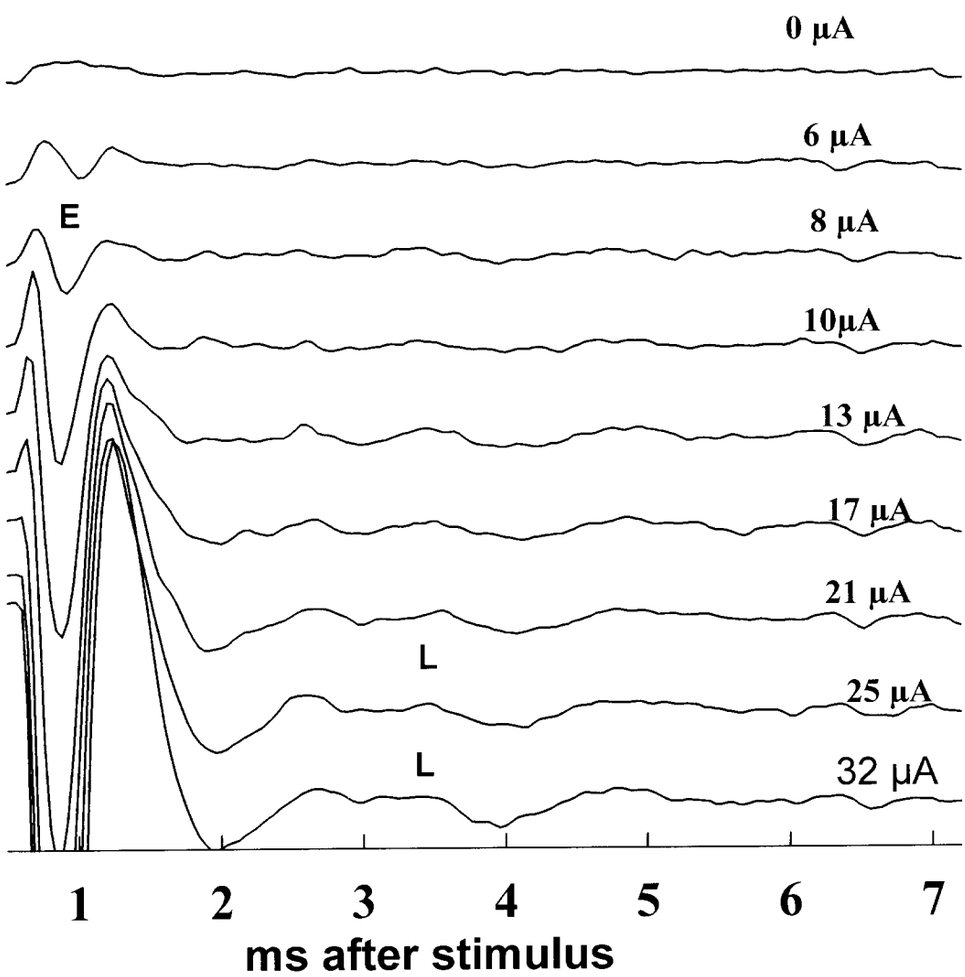


Figure 2B

Cat sp104, 2 hours after implantation of the array.
Response evoked from microelectrode #1 and recorded from the ventral roots.
Stimulus pulse duration is 150 µs/phase (cathodioc first)
Stimulus pulse ampltude is listed adjacent to each trace (337.tra)



sp104a.spw

Figure 3